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Short Communication

Precipitation differences cause contrast patterns of glacier-melt water supplied discharge of two glacier basins between northern and southern Third Pole

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In the Third Pole (TP) region, there are about 100,000 km^2 of glaciers [1], distributed mainly in the Tibetan Plateau and its surroundings. Glacier melt-water from these glaciers not only feeds rivers, such as the Indus, Brahmaputra, Ganges, Yellow and Yangtze, which finally reach the seas, but also feeds the rivers, such as the Tarim River, Heihe River and a lot of other rivers, which finally reach the arid areas or deserts. The Asian Water Tower [2] is, therefore, proposed to characterize the significance of the glaciers and glacier melt water at all the river heads in the TP, which is important water resource both for regulating seasonal water demands in the arid areas or deserts and for sea level rising. In addition, they also change the water cycle at a large scale [3].

Glacier melt is closely related to climate change. During the last several decades, temperature in the TP is rising remarkably and causing intensive glacier melt. Previous study has projected that glaciers in the southern TP are melting much more rapid and would have reduced to 50% of its area by the mid-21st century [4]. It has been found that glacier status is mainly precipitation dependent in the northern TP [5] while it is more temperature dependent in the southern TP [6]. Studies have also found that atmospheric circulation systems, which are closely related to weather patterns, control precipitation and are shifting with climate warming and impacting glacier melt status [6]. At present, a weaker Indian monsoon is reducing precipitation in the southern TP, resulting in a more intensive glacier melt; while a stronger westerly is increasing precipitation in the northwest TP, resulting in less glacier melt or even advancing glacier status [2].

Temperature rise accompanied glacier melt water has already caused serious consequences. Glacier melt water supplied lakes are shrinking in the southern TP due to the weaker Indian monsoon and expanding in the northern TP due to the stronger westerly [7]. In 2016 and 2018, unprecedented glacier collapses brought glacial till to make the Aru Lake tsunami [8] and to dam the Yarlung Tsangpo River, respectively. These glacier collapses either killed local residents or caused serious flooding as far as India. Although it has been pointed out that the peak of glacier melt supplied discharge might be earlier with climate warming, there is little information about the long term characteristics of glacier melt water supplied discharge [9]. Communities in or near the mountains need such information to help them predict future glacier melt water supplies and manage glacier melt water related risks. They need to know which glaciers are melting more intensively and causing more serious hazards and how changing glacier melt water supplied discharge in a warmer climate will affect their future. It is particularly interesting to know how glacier melt water supplied discharges has been changing in the monsoon dominated region and the westerly dominated region in the future. With accumulation of in-situ observation data, it is now the time to study such interesting topics.

In this study, we have selected the Qiyi Glacier and its related basin, the Tuole River basin, in the westerly dominated northern TP, and the Yala Glacier and its related basin, the Langtang River basin, in the Indian monsoon dominated southern TP, to clarify the characteristics of glacier melt and glacier melt water supplied discharge. The Qiyi Glacier, with an area of 2.76 km^2, is located in the Qilian Mountain in the northern TP (Fig. S1 online). The Yala Glacier, with an area of 1.9 km^2, is located on the southern slope in the central Himalayas (Fig. S1 online). Both the Qiyi Glacier and the Yala Glacier are without debris cover over glacier surface.

The reason to select these two glacier and the two basins with the two glaciers for a comparative study is that both the glacier melt, (or mass balance in another word) data and hydrological observation data are relatively in good quality. Glacier mass bal-

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ance measurement started in the 1970s for both the Qiyi Glacier and for the Yala Glacier by glaciologists. Glacier melt water supplied discharge observations are operating by Ministry of Water Resources of People's Republic of China for the Tuole River and by Department of Hydrology and Meteorology of Nepal for the Langtang River. There were many studies in glacier mass balance and glacier melt water supplied discharge previously in both regions [2,10–15]. We have compiled all the data from the above mentioned agencies and the previous studies in a way for a comparative study.

Glacier melt is climate driving, mainly through temperature and precipitation. It is, therefore, important to know the two most crucial parameters to further analyze glacier melt processes. The two meteorological stations close to the two glaciers are the Tuole Meteorological Station which is about 100 km away from the Qiyi Glacier and the Kathmandu Meteorological Station which is about 70 km away from the Yala Galcier (we do not use the data from the closer Langtang Meteorological Station because the data set is not continuous). Air temperature recorded at the Kathmandu Meteorological Station is increasing, while precipitation decreasing (Fig. 1a and c). At the Tuole Meteorological Station, meteorological records show that air temperature is keeping the same pace with rapid warming as in the Kathmandu station, while precipitation is contrasting to that at the Kathmandu Station, with an obvious increasing trend (Fig. 1b and d).

Glacier melt is directly measured by glacier mass balance, which is mainly driven by ice and snow melt and snow accumulation. The major components controlling ice and snow melt and snow accumulation are temperature and precipitation and finally represented by glacier mass balance. Glacier mass balance measurement for the Qiyi Glacier started in 1973, stopped in 1988 and restarted in the early 1990s. Glacier mass balance was positive before the 1990s and became negative in early 1990s. Glacier mass balance of the Qiyi Glacier was still +38 mm in 1987, around −200 mm from the early 1990s to the early 2000s, about −550 mm after 2006 (Fig. 2a) [10]. The glacier mass balance measurement for the Yala Glacier started in 1974, measured from time to time afterwards, and became continuous in the early 2000s. The Yala Glacier experienced more and more negative glacier mass balance from about −280 mm between 1974 and 2006 to about −760 mm after 2006 (Fig. 2b) [11,12]. Overall, The Qiyi Glacier is characterized by low melt and low accumulation while the Yala Glacier by high melt and high accumulation. The significant differences in mass balance occurred between the Qiyi Glacier and the

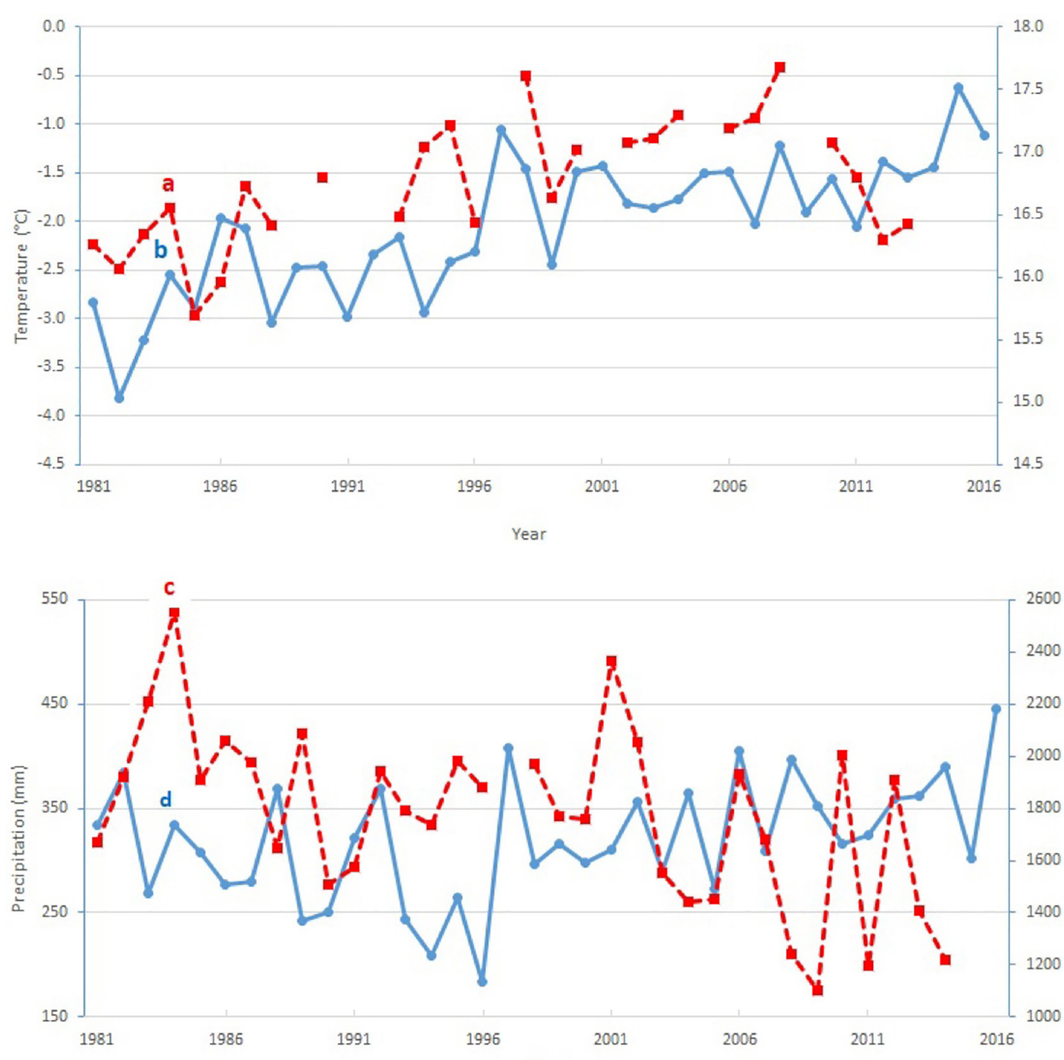

Fig. 1. Temperatures and precipitations at the Kathmandu Meteorological Station near the Yala Glacier located in the central Himalayas and Tuole Meteorological Station near the Qiyi Glacier in the Qilian Mountain. In the figure, a and b stand for the temperatures at the Kathmandu and Tuole Meteorological Station, c and d stand for the precipitations at the Kathmandu and Tuole Meteorological Station.

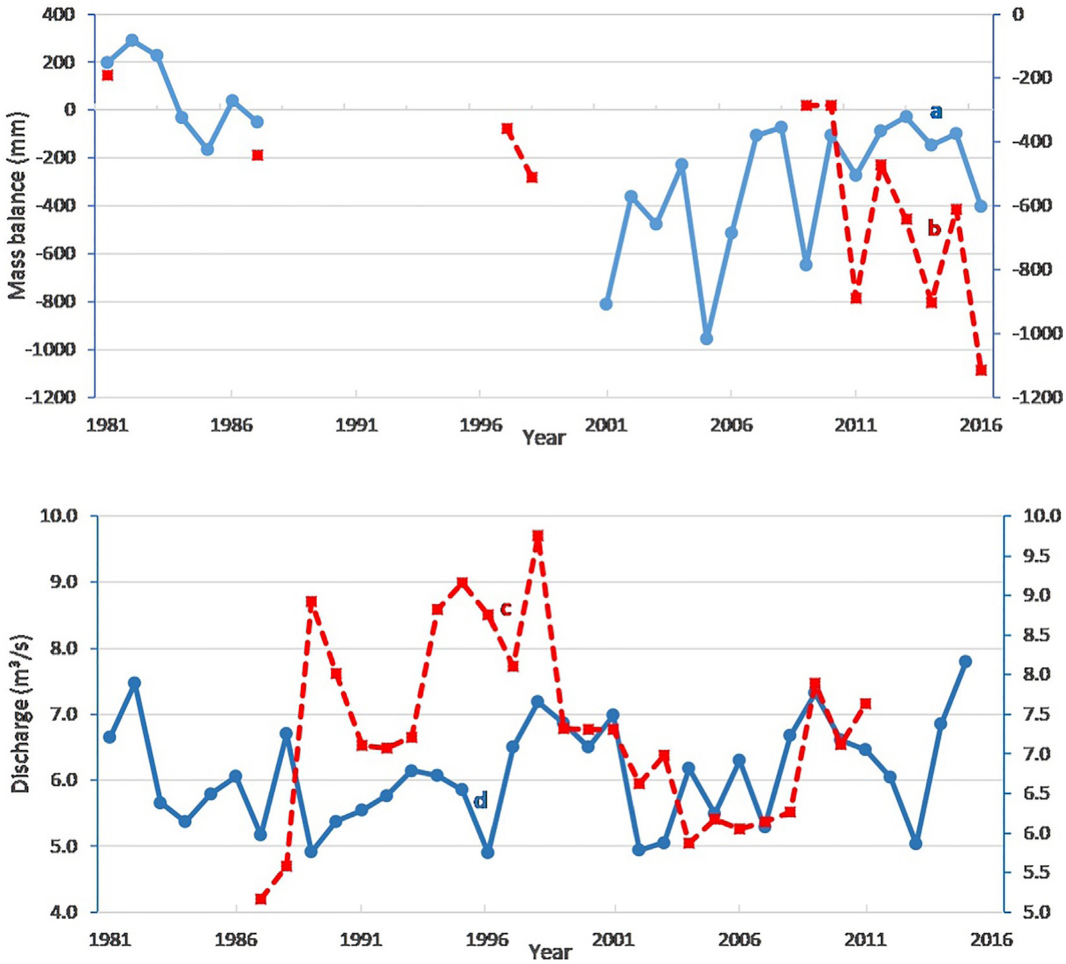

Fig. 2. Glacier mass balances for the Qiyi Glacier and Yala Glacier, and the glacier melt water supplied discharges in the Tuole River basin and Langtang River basin. In the figure, a and b stand for the glacier mass balances of the Qiyi Glacier and Yala Glacier, c and d stand for the observed discharges in the Langtang and Tuole River basin.

Yala glacier mainly result from their differences in surface snow and ice melt during the ablation season.

The contribution of the major components for the discharge defines the characteristics of the discharge in a river basin. Most river basins originated from the TP are characterized by small amount of glacier melt water supply because of small scale of glaciers. The major fluctuations of most glacier melt water supplied discharges are basically precipitation driving. The two glacier melt water supplied discharges in the Langtang and Tuole Rivers are in this type. It is clear from Fig. 2c that the Yala Glacier melt-water supplied discharge in the monsoon dominated Langtang River basin is decreasing (Fig. 2d). The explanation is that the precipitation is decreasing in the southern TP. And consequently, the increased glacier melt-water contribution cannot compensate the decrease of precipitation and cause the discharge decreasing. However, the Qiyi Glacier melt-water supplied discharge in the westerly dominated Tuole River basin is increasing (Fig. 2d). Since both increasing glacier melt and increasing precipitation contribute to the discharge in the Tuole River basin, the two processes bring more water into the river and cause the discharge increasing.

In summary, both the westerly dominated Qiyi Glacier and the monsoon dominated Yala Glacier are experiencing negative mass balance under current climate warming. Differences are obvious for the two glaciers: it is characterized with precipitation increase in the Qiyi Glacier related Tuole River basin where the westerly dominates, while it is characterized with precipitation decrease in the Yala Glacier related Langtang River basin where the Indian monsoon dominates. Although the two glaciers show very negative mass balance, their glacier melt water supplied discharges are changing differently with increasing characteristic in the Qiyi Glacier related Tuole River basin and decreasing one in the Yala Glacier related Langtang River basin, corresponding to increasing precipitation in the enhancing westerly and decreasing precipitation in the weakening Indian monsoon, respectively. We have made M-K tests of the precipitation and glacier melt water supplied discharge increasing or decreasing trends in the two river basins. The M-K test results for precipitation and glacier melt water supplied discharge increasing or decreasing trends in the two river basins have not shown obvious shift and not passed 95% significance either. The precipitation and glacier melt water supplied discharge increasing or decreasing trends are, therefore, observable but not obvious.

Conflict of interest

The authors declare that they have no conflict of interest.

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Author contributions

Ruzhen Yao proposed conception, carried out data analysis, and model results analysis, complemented draft writing. Jiancheng Shi revised the draft and edited the final submission.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scib.2019.03.018.

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Ruzhen Yao is a Ph.D. candidate at the Aerospace Information Research Institute, Chinese Academy of Sciences. She is studying the processes of glacier melt supplied discharge in different glaciers and the supplied river basins in the Tibetan Plateau under the current climate warming. Her research inerest focuses on the study in a comprehensive approach by combining in-situ observation data and modeling data.